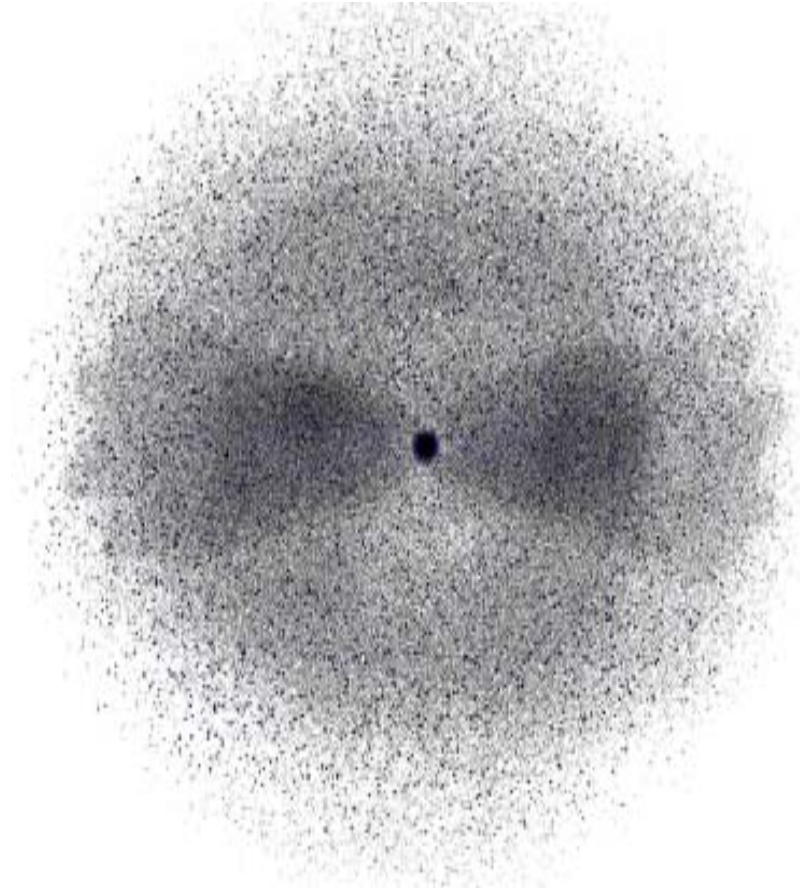


# An Oort cloud analogue in an extrasolar protoplanetary region ?

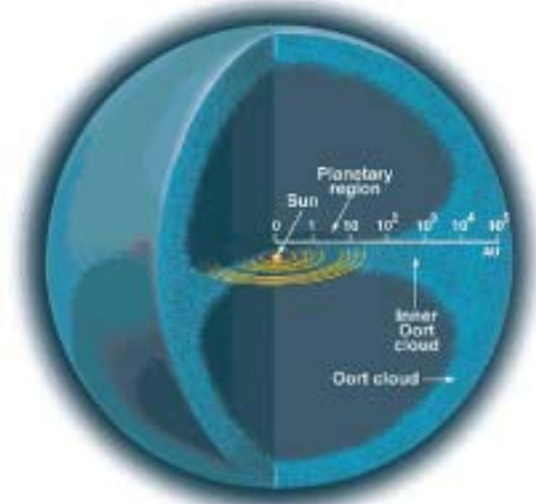


**Glenn J White<sup>1</sup>, C. V. Malcolm Fridlund<sup>2</sup>, Per Bergman<sup>3</sup>, Anji Beardsmore<sup>1</sup>, René Liseau<sup>4</sup>,  
René Laureijs<sup>2</sup>, Göran Pilbratt<sup>2</sup>, A J Markwick<sup>4</sup>**

1. University of Kent, England
2. ESTEC, The Netherlands
3. Onsala Space Observatory, Sweden
4. Stockholm Observatory, Sweden

# Protoplanetary Disks – a quick overview

- Protoplanetary disks represent an early stage of planet formation – billions of small icy bodies
- At high densities and low temperatures most molecules deplete out onto dust grains
- Chemical models predict most molecules form in the inner regions – or on the surfaces of (flared) disks
- Methanol is one of the more abundant, and important chemical species, observed abundantly in comets
- The presence of accretion disks are often associated with energetic outflows and luminous sources
- In this presentation we report the detection of spatially extended, thermally excited methanol, in an outer protoplanetary disk ( $> 8000 - 15,000$  AU). This would extend out well into the boundary of the equivalent terrestrial Oort cloud in our solar system

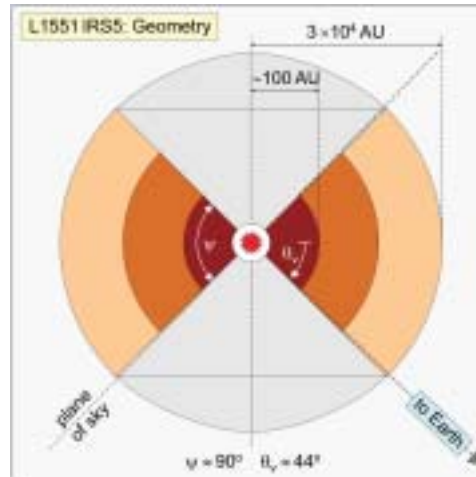
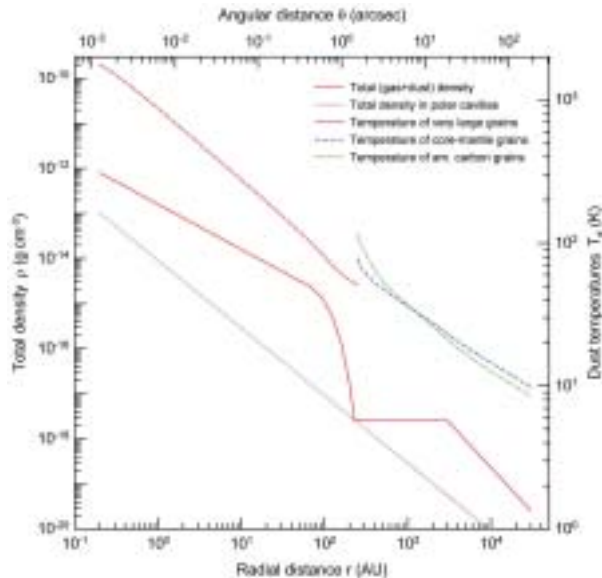
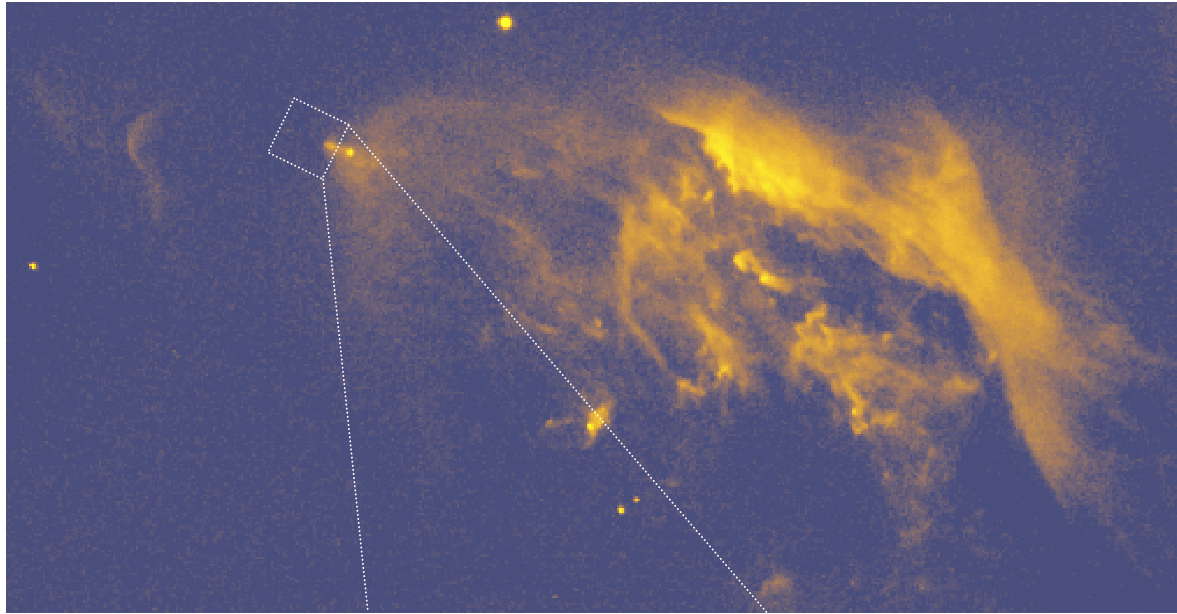


- We argue that the methanol has probably been driven from the denser circumstellar disk by an external energy source, such as the x-ray or UV emission, or processes associated with the the outflow wind
- We suggest that the rapid depletion of the methanol onto grain surfaces will lock this material into small icy bodies in an L1551 Oort cloud analogue, providing early time chemical complexity that could rapidly drive the subsequent formation of a rich organic chemistry on the surfaces of future (and present ?) comets and icy bodies.

# The Lynds 1551 Star Formation region

- Lynds 1551 is a nearby dark cloud, with a prominent molecular outflow and a centrally condensed  $0.6 M_{\odot}$  protostellar disc surrounded by an outer disc with a total system mass  $\sim 2.5 M_{\odot}$  - central disk seen in many molecular tracers and in dust – total mass  $\sim 15 M_{\odot}$
- It contains a young binary pair of Class I protostars separated by 45 AU (0.3'') with a total mass  $\sim 1 M_{\odot}$  – the stage of planet formation remains unclear
- Two parallel jets emanate from the core, and a massive molecular outflow is seen – probably driven by angular momentum transfer from the disc
- Evidence for/against rotation has been controversial – but now believed to show both rotation + infall + clumpy central structure
- L1551 is surrounded by a large (20,000 AU) core halo disc, illuminated by x-ray and UV emission,  $\sim 1000$  AU above the disk, that provides external heating of the disk surface.  $3.54 \mu\text{m}$  solid state methanol line seen in disk (White et al 2000), , giving high ratio of solid  $\text{CH}_3\text{OH} / \text{H}_2 \sim 10^{-4}$  cf Leiden observations of disks
- The outflow energetics require ionisation fractions at the disk surface  $\sim 10^{-6}$

# Lynds 1551



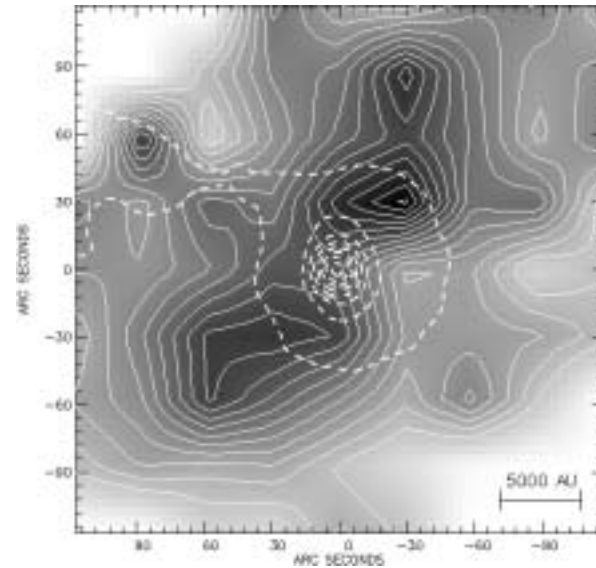
Main input parameters of the IRS 5 model

| Parameter                     | Value                                   |
|-------------------------------|---|
| Distance                      | 160 pc                                  |
| Central source luminosity     | $45 L_{\odot}$                          |
| Stellar effective temperature | 5500 K                                  |
| Flared disc opening angle     | $90^{\circ}$                            |
| Viewing angle                 | $44^{\circ}5$                           |
| Torus dust melting radius     | 0.2 AU                                  |
| Torus outer boundary          | $3 \times 10^4$ AU                      |
| Torus total mass (gas+dust)   | $13 M_{\odot}$                          |
| Density at melting radius     | $8.0 \times 10^{-13} \text{ g cm}^{-3}$ |
| Density at outer boundary     | $2.6 \times 10^{-20} \text{ g cm}^{-3}$ |
| Outflow visual $\tau_v$       | 10                                      |
| Midplane $\tau_v$             | 120                                     |

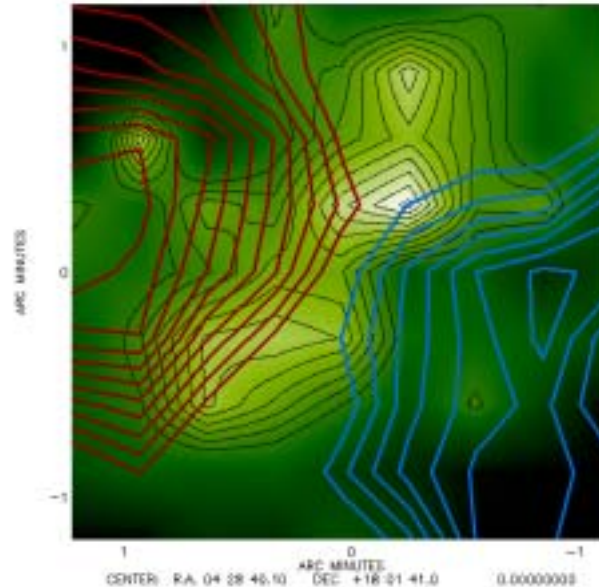
# Methanol disc in Lynds 1551

- Using observations with the Onsala 20m and JCMT 15 metre telescopes at mm wavelengths, we have mapped the L1551 circumstellar disc in two transitions (96 and 241 GHz), allowing us to model the excitation and molecular abundances

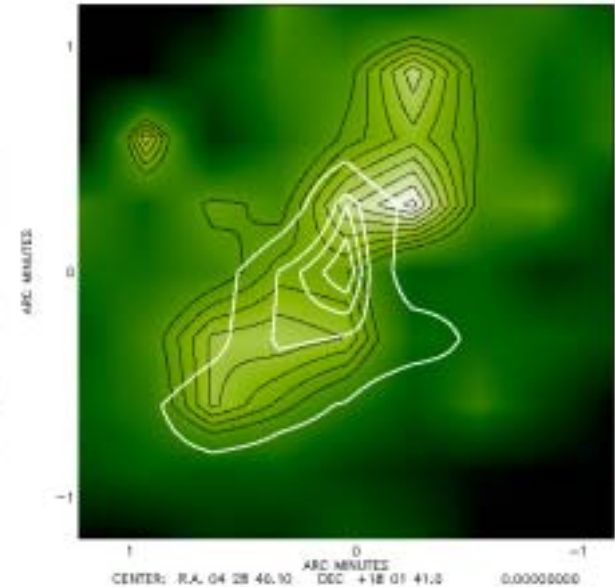
**Methanol (solid)**  
**Dust (dotted)**



**Methanol (green)**  
**CO (red/blue outflow)**



**Methanol (green)**  
**HCN (white solid)**

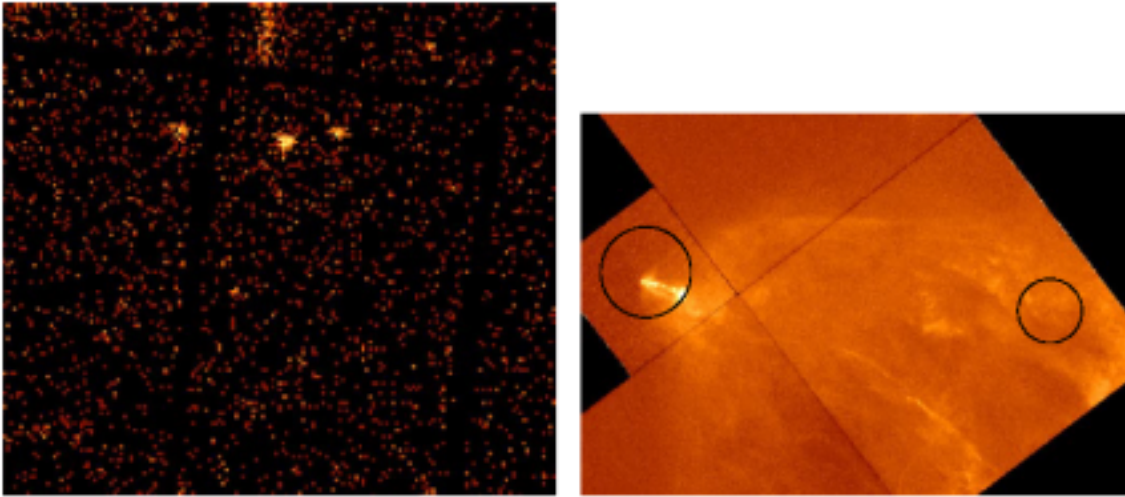


- The methanol is thermally excited, cool ( $T_{\text{kin}} \sim 6$  K), and has a high abundance ( $X$ ) relative to  $\text{H}_2$ ,  $\geq 2 \times 10^{-8}$ , cf dark clouds,  $X \sim 10^{-10}$  - few  $\times 10^{-9}$  and hot cores ( $X \sim 10^{-7}$  -  $10^{-6}$ ). The  $\text{H}_2$  density of the  $\text{CH}_3\text{OH}$  at 10,000 AU is  $\sim 10^4 \text{ cm}^{-3}$ , and the column density is  $2 \times 10^{13} \text{ cm}^{-2}$  (cf L1551 core  $\sim 2$  times larger)
- The low temperatures at 10,000 AU ( $< 10$  K) suggest that the methanol must have been desorbed out from warm (inner ?) dust grains - and will soon deplete to (outer) grains or icy bodies within  $< 10^5$  years.

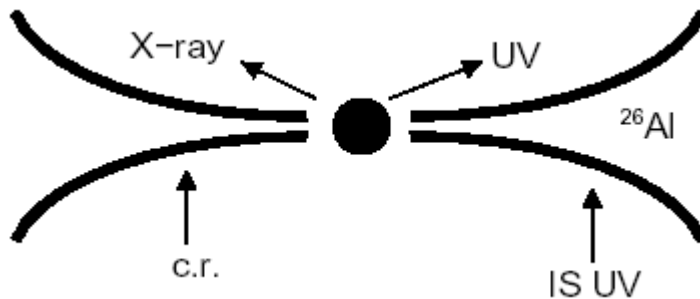
# Formation and Desorption mechanisms

- Methanol depletion time  $\sim 10^9/n(\text{H}_2) \sim 10^5$  years,  $\leq$  age of the L1551 system  $\rightarrow$  replenishment of gas phase methanol. Disk gas/solid column density ratio  $\sim 10^{-4}$
- At least a 20 Habing radiation field, or non-dissociative shock is necessary to desorb  $\text{CH}_3\text{OH}$  from in the central core – it is unlikely that significant amounts of  $\text{CH}_3\text{OH}$  ( $X > 10^{-11}$  – Viti private communication) could be formed in the gas phase on appropriate timescales for this system
- The detection of substantial amounts of gas phase methanol in the outer part of the disk suggests that the methanol has been desorbed from warmer grain material, after formation in the denser protostellar core (Goldsmith et al 1997 L1157 on 200 AU scale)
- Few chemical models have considered  $\text{CH}_3\text{OH}$  formation with simple flared disks, first generation models (Willacy & Langer 2000), Semenov, Weibe & Henning 2004), substantially underestimate the abundances observed, whilst that of Aikawa et al (2002) approaches our observational results. However, these models are for distances  $< 400$  AU from the central star – and do not explain the high abundances at  $\sim 10,000$  AU
- The primitive organic chemistry in the outer protostellar envelope of L1551 may be substantially modified as a result of expelled material from the central disk. Rotation  $< 0.04 \text{ km s}^{-1}$  at 10,000 AU

# L1551 x-ray emission



Favata, Fridlund et al A&A 386, 204, 2002, Bally et al 2003



Markwick et al 2004

It remains unclear what the line of sight absorption from the external sources to the disc surface is, nor how long the external radiation sources will shine for.

It is however likely that a similar model is required to desorb material from the hot central core, where the methanol forms by grain surface reactions, returning it to the outer part of the disk to become incorporated into L1551's Oort cloud

# Observations – and unresolved issues

## *Observational Conclusions*

- Observations suggest that substantial chemical processing occurs within the disk with desorption near the core, and subsequent depletion in the outer Oort-like regions
- Methanol desorbed from the grains is returned to the icy grain mantles in the cooler outer regions, to become part of the composition of solar-like bodies, such as comets in the outer circumstellar envelope
- This detection indicates the influence of the environment close to the star forming region, on the evolution of material in the disk, following desorption and re-depletion
- The primitive organic chemistry in the outer protostellar envelope of L1551 may be substantially modified as a result of expelled material from the central disk

## *Some outstanding problems*

- Where is the water ? – lack of ISO, ODIN or SWAS lines – but probably due to cold medium – no substantial excitation
- What is the longevity of the x-ray or UV emission – can it sustain the heating ?

# Conclusions

- We report the first mm wave detection of a complex organic molecule in the outer part of a protostellar disk
- Methanol emission is seen in two condensations located  $\sim 10,000$  AU on either side of the central star forming disk, appearing as an shell
- The methanol is cold ( $T_{\text{kin}} \sim 6 - 10\text{K}$ ), dense ( $N(\text{H}_2) \sim 10^4 \text{ cm}^{-3}$ ), unexpectedly abundant ( $X = > 2 \times 10^{-8}$ ), and has a column density  $\sim 2 \times 10^{13} \text{ cm}^{-2}$ . at 10,000 AU
- Chemical models can not support such high methanol abundances resulting from gas phase reactions, and require a way of returning gas from the central core to the outer disk – most likely by desorption from the surface of a flared disk – heated by one of a number of potential energy sources close to the L1551 protostellar binary system
- The methanol will deplete onto grain surfaces in  $\leq 10^5$  years, becoming assimilated onto dust grains, and freezing information about the nebular abundances in the outer icy bodies
- The outer envelope dust grains aggregate, forming icy outer disk L1551 bodies such as comets – the precursor material to the L1551 Oort cloud – the beginning of chemical complexity

